Wireless ECG

Final Report

By

Mike Chester - V00711672

James Hollinger - V00688750

Tristan Sturgess - V00684498

John Tran - V00704411

Group: 13

Supervisor: Xiaodai Dong

Due: December 3rd, 2012

Dept. Electrical and Computer Engineering

University of Victoria

Table of Contents

Table of figures ii
1.0 Goals 1
1.1 Background 1
1.2 Motivation 1
1.3 Scope 2
2.0 Project Overview 3
3.0 Detailed Project Description 4
4.0 Project Discussion 5
4.1 ECG Sensor Overview 5
4.1.1 ECG Sensor Design 7
4.1.2 Electrode Design 8
4.2 Bluetooth Transmitter 9
4.2.1 Advantages of the cc2540 10
4.2.2 Disadvantages of the cc2540 10
4.3 Filtering Implementation 11
4.3.1 Initial Filtering 12
4.3.2 Filtering Movement Artifacts with Accelerometer Input 12
4.3.3 Filtering Movement Artifacts with Skin Impedance Sensors 14
4.3.4 Identifying Common Issues 15
5.0 Summary and Future Works 16
5.1 Future Design for Sensor 16
5.2 Future Testing for Adaptive Filtering 16
5.3 Future Collaborative Work 17
8.0 References 18

Table of figures

Figure 1 - 12 Lead ECG Configuration 6
Figure 2 - 12 Lead Criteria.. 6
Figure 3 - ECG Waveform... 7
Figure 4 - Sensor Suspenders Example 8
Figure 5 - Insulated Dry Electrodes 9
Figure 6 - Recorded ECG and Accelerometer Signals 13
Figure 7 - Block Diagram of an Adaptive Filtering System.................................... 14

1.0 Goals

1.1 Background

Routinely, the cycle of a heart is measured in a clinical setting using an electrocardiogram, or ECG. However, ECGs require 10-12 wired probes placed in direct contact with the skin. This requires irritating adhesives, conductive gels, and may require special treatments such as shaving the chest of the patient. Because of these factors, ECGs are typically stationary devices and are not suited for long term monitoring. It is important, however, to continually monitor the heart signal of patients at risk of cardiovascular arrhythmia or other heart diseases. An ideal solution would involve a durable portable system that could be used by a patient without assistance and with a minimum of training.

1.2 Motivation

The principle motivation for this project is to develop a method of monitoring heart activity for patients with heart disease, pacemakers, and other special heart conditions so the patient can lead a relatively active life without being confined to a specific region. The current 12-lead ECG systems in use are uncomfortable, non-portable, invasive and unsuitable for long-term use. By being able to monitor sickly patients remotely, peace of mind can be offered to extended family knowing that emergency services can be dispatched in the event of cardiac arrest, or irregular heart patterns.

1.3 Scope

To that end, the project that our group has chosen for ELEC 399 is a Wireless Electrocardiogram. The purpose of this device is to transmit data about a person's heart rate in real time, using non-intrusive, low power, band-aid sized probes to a smartphone. The smartphone will receive the output from the ECG via bluetooth and either store it for later analysis or upload it for analysis in real time. The smartphone will also be able to detect when the output indicates a medical emergency, such as cardiac arrest, and call an ambulance on behalf of the patient. The software used by the application on the smartphone will be addressed by another group.

2.0 Project Overview

The purpose of this wireless ECG device is to transmit data about a person's heart rate in real time, using a non-intrusive, low power, band-aid sized probes to a smartphone. The smartphone will receive the output from the ECG via Bluetooth and either store it for later analysis or upload it for analysis in real time. The smartphone will also be able to detect when the output indicates a medical emergency, such as cardiac arrest, and call an ambulance on behalf of the patient. The idea behind our project was to improve upon an existing wireless ECG design. The sensors used in the current design were not performing to meet our expectations and would require the patient to remain still in order to receive a useable signal. Our group also invested time in improving on the filtering performed to the ECG signal data as analyzing an ECG signal is the idea behind the project, having a usable signal is of the utmost importance. We also took some time to look at the current bluetooth transmitter in use and became familiar with its functionality.

3.0 Detailed Project Description

The ECG sensor is a 5-lead/electrode system embedded in a suspender peripheral. The electrode will be an insulated type because it is non-intrusive and is comfortable for the patient. This design avoids the need for irritating adhesives and exposed wire. This sensor is designed to be non-intrusive and easy to install.

The signal will be captured using a differential amplifier, and will then be filtered and amplified to increase fidelity. The signal will first be passed through a low pass filter to remove high frequency and power line noise before being amplified. Since movement artifacts can add noise to the signal, optical stretch sensors and three axis accelerometers will be used to infer the induced motion noise. This will feed into an adaptive filter in a microcontroller and will be used to further filter the ECG signal.

The signal will then be sent via the Texas Instruments cc2540 low-power Bluetooth chip. This chip was selected due to its small form factor, low system and monetary cost, and low power. Although only the IPhone 4 current supports low power Bluetooth, it is expected to be universally adopted by the smartphone market by the time the ECG is fully developed.

4.0 Project Discussion

4.1 ECG Sensor Overview

We require a non-intrusive sensor to be mounted on the chest of a patient to receive the electrical signal from the heart. Ideally, this ECG sensor must meet the following criteria:

1) Have minimal surface area.
2) Simple installation and removal.
3) Non-irritating.
4) Can be mounted for long periods of time.
5) Non-intrusive such that the patient can perform daily activities.
6) Resistant to movement, sweat, and external noise.

A typical ECG contains 12 leads and 10 electrodes. There are 6 electrodes mounted across the chest between the 4th and 5th intercostal spaces in the ribcage, as well as 4 others mounted to each limb in the body. This arrangement is shown below in figure 1. There is a common misconception between leads and electrodes. Each lead represents a viewing of the heart from a different angle, while an electrode or electrode wire is the physical device that is being mounted on the body.

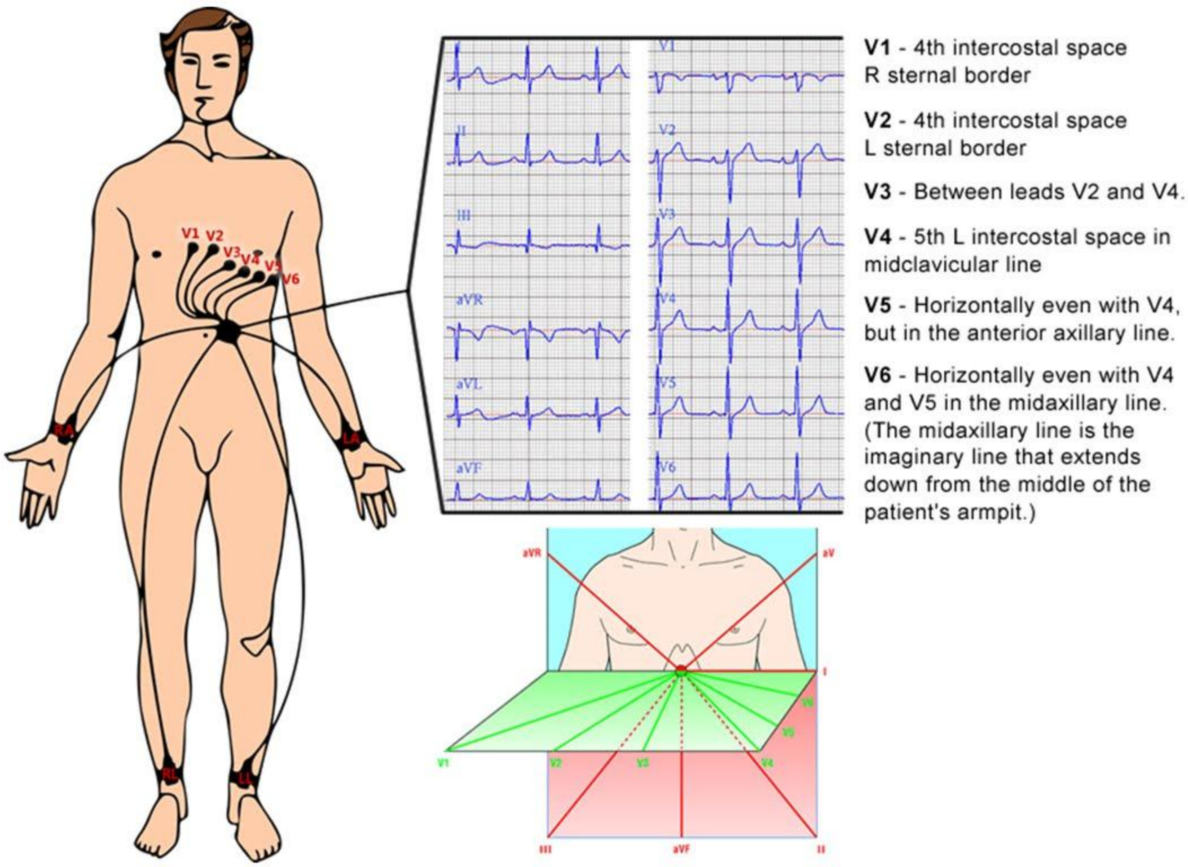

Figure 1 - 12 Lead ECG Configurations [1]

I Lateral	aVR	V1 Septal	V4 Anterior
II Inferior	aVL Lateral	V2 Septal	V5 Lateral
III Inferior	aVF Inferior	V3 Anterior	V6 Lateral

Figure 2 - 12 Lead Criteria [1]

4.1.1 ECG Sensor Design

We chose a 5-lead ECG design because it gives information on the ST segment in the standard heart waveform, illustrated in figure 3, below. This is useful because if we can detect ST elevation we will be able to better detect myocardial infarction (heart attack) and if we can detect ST depression we will be able to detect conditions such as Digoxin Toxicity and Hypokalemia [2].

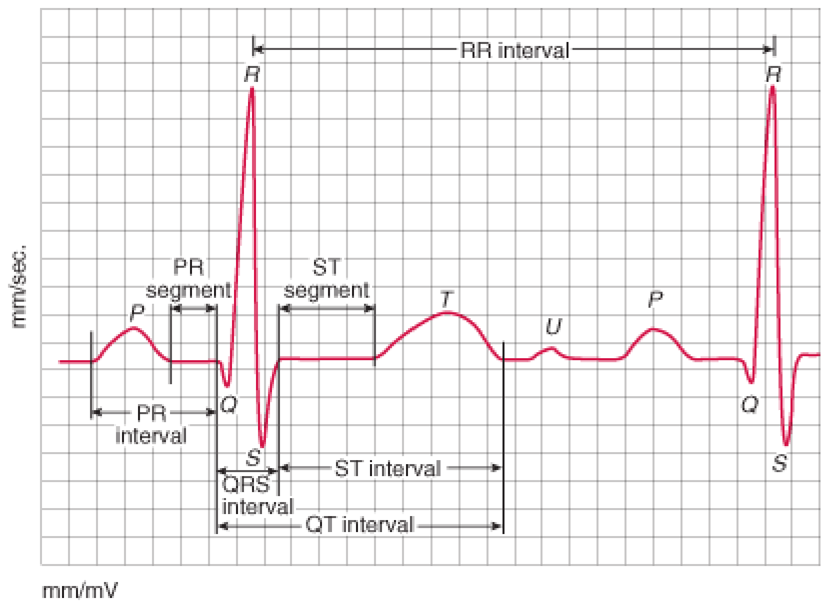

Figure 3 - ECG Waveform [3]

What differentiates our design from an ECG in a typical hospital setting is that it is secured by x shaped suspenders. They can be worn as normal suspenders directly on the skin, except the anterior and posterior sections switch places. The suspenders can easily be tightened and adjusted in accordance to the size of the patient.

Figure 4 - Sensor Suspenders Example [4]

The 5 probes required should be attached to the suspenders such that they coincide with sections V1-V6 in the ECG configuration. By using a suspender peripheral the wires and electrodes connecting the probes to the microcontroller can be stabilized.

4.1.2 Electrode Design

The selected electrode design was chosen to be of an insulated type. An insulated electrode was selected because it does not require electrolytic pastes or adhesives to hold it in place [5]. To put it simply, we can use cotton or silk as our insulating layer, which is no different than what normal clothing contains. This allows the leads to sit on the patient for long period without using any irritating gels or liquids on the pads. According to De Armas, a copper foil electrode is best suited for this application because the entire foil is conductive [5]. This is especially important in case the electrodes within the suspenders need to be moved.

Figure 5 - Insulated Dry Electrodes [6]

4.2 Bluetooth Transmitter

A transmitter is required to send the signal from the sensor to the smartphone. Ideally, it should be as small and low power as possible and should interface with the receivers already present on the phone. To that end, the Texas Instruments cc2540 low power Bluetooth system-on-chip was chosen to meet the requirements.

4.2.1 Advantages of the cc2540

The cc2540 chip is quite robust, providing the signal strength needed for our application with a small form factor and very low power. The chip also has a number of built-in features that would otherwise have to be programmed or hard wired in, such as a battery monitor, temperature sensor, and signal strength monitor. The chip measures 4.5mm by 4.5mm and so is uses little room on our PCB. Since the transmission distance in our application will be only around 1m, the chip can run at low signal strength, drawing as low as 20 mA. It also conforms to standardized worldwide transmission regulations. Despite the multitude features on the chip, it is still a mass-produced semiconductor and therefore the unit price is around $2.5 when ordering in the hundreds. These features allow the chip to be integrated into our hardware inexpensively, from a price, PCB real estate, and system and battery cost perspective. Additionally, the chip has a development kit and has several example projects similar to ours, simplifying the integration of the chip into our software.

4.2.2 Disadvantages of the cc2540

The primary disadvantage of the cc2540 is the lack of compatibility for low power Bluetooth among smartphones. Currently, the only smartphone compatible with low power Bluetooth is the IPhone 4. However, this standard is being adopted by cell manufacturers and we fully expect non-Apple phones to be compatible by the time the ECG is fully developed. Making the ECG compatible with Android or other non-Apple phones would require some additional software work but would increase the market for the device. IPhone has an approximately 33% market share in cellular phones, and so prospects for the device are still optimistic if android does not adopt the low power Bluetooth standard [7].

The second disadvantage of this chip is that low power Bluetooth has a lower bandwidth than standard Bluetooth. However, the range of data required in our application is quite small, so this limitation should be manageable. If there are concerns with bandwidth as the project develops, this issue can be solved in several ways. First, full power Bluetooth or another transmission standard could be adopted to increase bandwidth. This would have adverse affects on compatibility with devices and would increase the power consumption. Secondly, some preliminary signal processing could be done by the hardware to reduce the bandwidth of the data. This would increase system and operating costs for the microcontroller and may increase power consumption, but would decrease the signal processing necessary by the software on the phone.

We feel the form factor, features and low power of the cc2540 chip outweighs the disadvantages and should be used by the project. The concern with compatibility will likely not be an issue, and the concern with bandwidth can be addressed as the project continues.

4.3 Filtering Implementation

There are several considerations for filtering the ECG signal. Most noise can be removed with a simple band-pass filter because the ECG signal is typically in a small low frequency band. However, there are also movement artifacts that typically create noise in the same band as the ECG signal itself, making them difficult to remove. The most effective way to remove movement artifacts without affecting the ECG signal is using an adaptive filter that has inputs from an external sensor. Provided there is a relationship between the external sensor output and the induced noise signal an adaptive filter should be able to reduce the induced noise.

4.3.1 Initial Filtering

Initial filtering is done to remove any part of the signal that cannot contain ECG information. The ECG signal can contain information from less than 1Hz to around 25Hz. The obvious first step is a low-pass filter with a cutoff frequency at 60Hz which would remove most high frequency noise including power line noise. A benefit of having the electrodes so close to the electronics is that shorter wires will reduce the noise caused by ambient electromagnetic fields and nearby power sources.

4.3.2 Filtering Movement Artifacts with Accelerometer Input

One of the options for an external movement sensor is a three axis accelerometer. Certain motions will cause artifacts in the ECG signal due to stretching in the skin under the electrodes or changes in the position of the electrodes relative to the heart. Figure 6 below shows a recorded ECG signal and the output from a three axis accelerometer that is attached to the electrode [8]. It seems clear that there is a relationship between the movement and the induced movement artifact (at approximately 0.5s and 3.0s). Further testing would have to be done to determine how effective this option would be but the premise is promising. The block diagram of the proposed system is shown in figure 7 below.

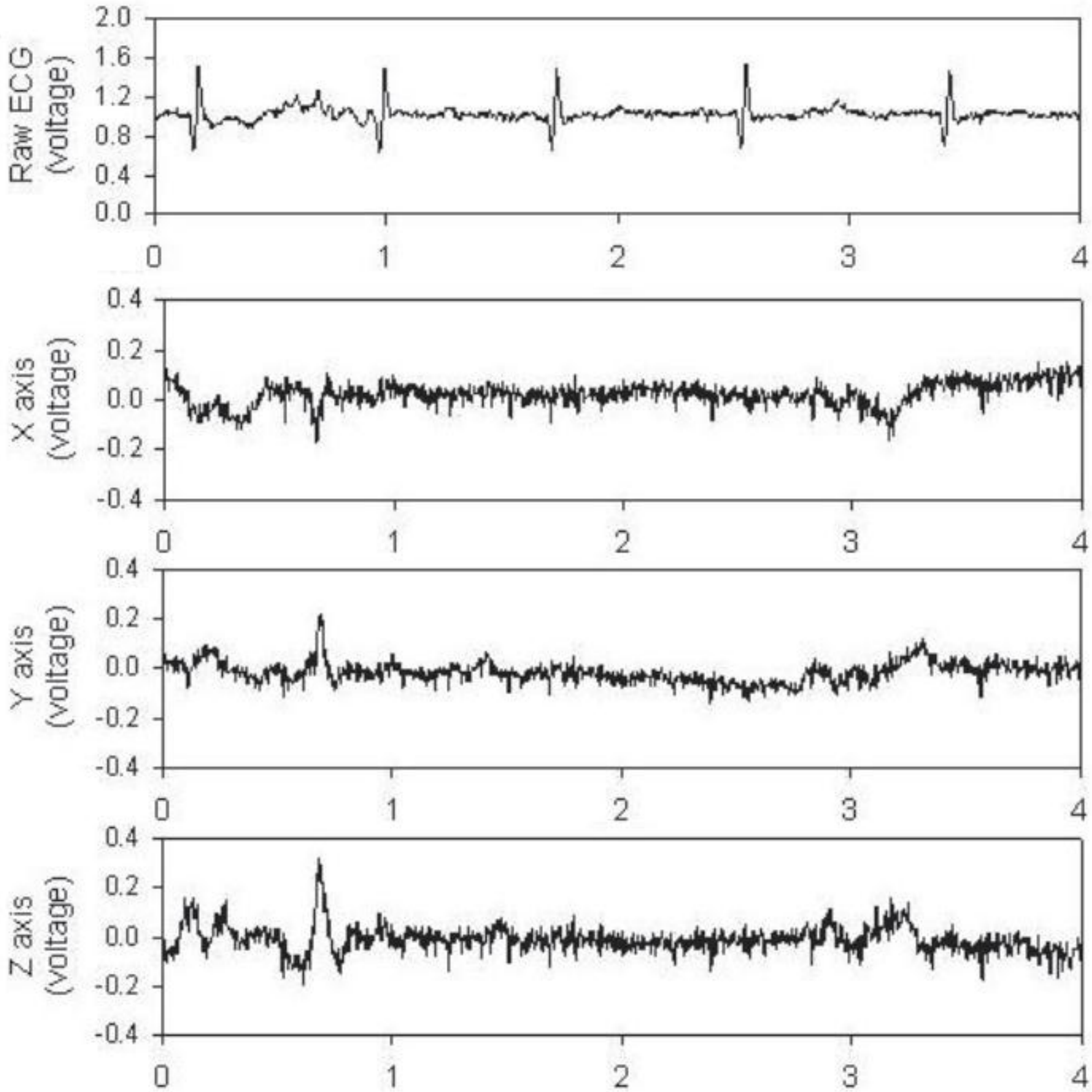

Figure 6 - Recorded ECG and Accelerometer Signals [8]

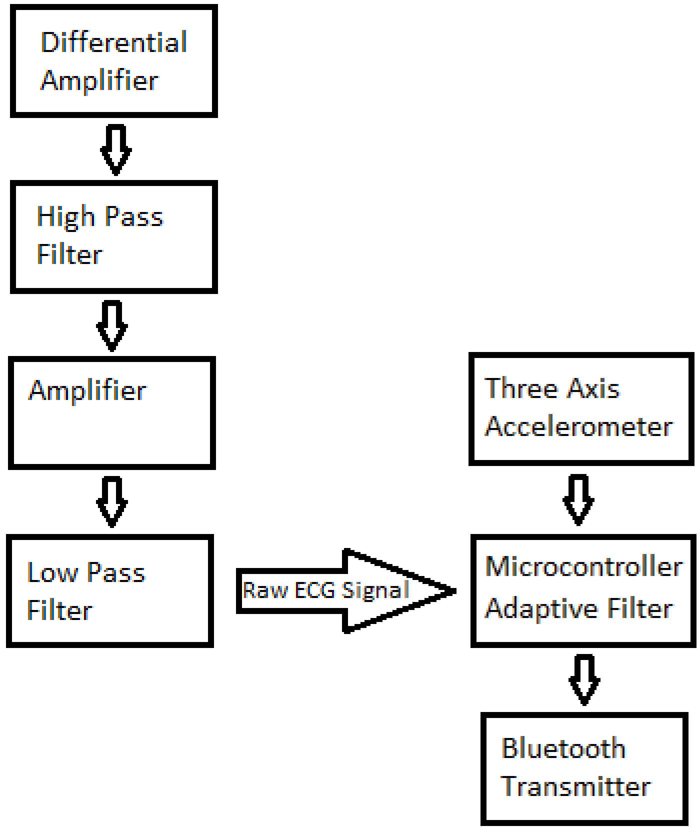

Figure 7 - Block Diagram of an Adaptive Filtering System [8]

4.3.3 Filtering Movement Artifacts with Skin Impedance Sensors

Stretching can change the impedance of the skin greatly which will affect the ECG measurement. Optical sensors can detect how much the skin is stretching and an adaptive filter should be able to use this input to remove some noise from the ECG signal. It seems likely that some relationship should exist between the optical sensor input and any ECG artifacts but this would need to be confirmed with testing.

4.3.4 Identifying Common Issues

Some artifacts can indicate a specific problem with the electrodes or electrode placement and it should be possible to alert the user if these artifacts are detected. Common problems with an ECG are loose and misplaced electrodes. In our setup the electrodes will be part of a unit which should reduce the chance of leads being misplaced but inversions will still be possible. In the absence of large artifacts, detecting an inversion is relatively simple as it causes an inversion of the signal in one of the leads. This should be easy to detect on the software end of the project. As well, disturbances in one lead but not the others could trigger a message telling the user to check the connection on that electrode.

5.0 Summary and Future Works

5.1 Future Design for Sensor

It is recommended that the leads connecting the wires and probes be protected from abrasion rather than allow them to lay exposed to external clothing. A suspender based design is strongly recommended for its simplicity and familiar application to patients. This design is currently limited to only a 5-lead system, but can also be reduced to a 3-lead system if desired. It would be theoretically possible to implement a 12-lead ECG system, however at this point it would become intrusive, defeating the purpose of the overall design.

5.2 Future Testing for Adaptive Filtering

The concept seems promising, however further testing is required to confirm the value of using the external sensor input. Ideally the 5-lead ECG data would be collected with data from an accelerometer, optical stretch sensor, and any other possible sensors to provide sample data for a simulation. The correlation between the movement detected by the sensors and the induced noise would then need to be imperially taken. MatLab and Simulink could be used to create the model of the filter for testing with the collected data.

5.3 Future Collaborative Work

A great deal of collaboration will be needed between the hardware design specified here and the software design necessary for the associated smartphone application. The format of the data sent by Bluetooth will need to be standardized between the hardware and software, and tradeoffs in hardware and software signal processing will need to be done. In the current design, only preliminary filtering and amplification will be handled by the hardware, while the more intensive DSP and pattern recognition will be handed by software. As well, more collaboration between both teams and medical professionals should be done. Their expertise and recommendations should factor into further features offered by the device.

8.0 References

1) “A Quick Guide To ECG” Internet:
http://www.ivline.info/2010/05/quick-guide-to-ecg.html
May, 2010 [December 1, 2012]

2) “Digoxin Effect” Internet:
http://lifeinthefastlane.com/ecg-library/digoxin-effect/
December 4th, 2012 [December 1, 2012]

3) Michael J. Shae, “Electrocardiography” Internet:
http://www.merckmanuals.com/professional/cardiovascular_disorders/cardiovascular_tests_and_procedures/electrocardiography_ecg.html,
May 1, 2009, [December 1, 2012]

4) “Men’s Regular Side Clip Suspenders” Internet:
http://www.duluthtrading.com/store/product/side-clip-suspenders-mens-regular-side-clip-suspenders-92992.aspx?src=T12WSHOP1
August, 2012 [December 1, 2012]

5) Winston De Armas, “Design of a Non-instrusive 2 –lead ECG System Using the Active Insulated Electrode” (2010). *EE 4BI6 Electrical Engineering Biomedical Capstones.* Paper 24.

6) “Active Insulated Electrodes” Internet:
http://www.bloomex.com/store/index.php?main_page=index&cPath=3_76
April 29, 2012, [December 1, 2012]

7) “Android vs. iPhone market share, 52 against 33 percent” Internet:
http://www.phonesreview.co.uk/2012/09/05/android-vs-iphone-market-share-52-against-33-percent/, September 5th, 2012, [December 1, 2012]

8) Shing-Hong Liu, "Motion Artifact Reduction in Electrocardiogram Using Adaptive Filter", Journal of Medical and Biological Engineering, vol. 31, no. 1, pp. 67-72, Feb 2010

9) Aaron Sparshott, “A Quick guide to ECG” Internet: http://www.ivline.info/2010/05/quick-guide-to-ecg.html, May 18, 2010, [December 1, 2012]

10) “Basics ECGpedia” Internet: http://en.ecgpedia.org/wiki/Basics#bibkey_Klootwijk, June 14, 2012, [December 1, 2012]